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Population dynamics of *Strongylocentrotus intermedius* in Akkeshi Bay

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Dynamics of the *S. intermedius* population in Akkeshi Bay was analyzed based on the age composition known by use of annual rings on the 5th genital plate. Between the number of annual rings (t) and the test diameter (D) or body weight (W), the following growth formulae were obtained.

$$D = 103.030 \left[1 - e^{-0.184 (t + 0.030)}\right]$$

$$W = 372.232 \left[1 - e^{-0.184 (t + 0.030)}\right]^{2.757}$$

The age composition of the population showed that young age groups have been decreasing and old ones increasing since 1975, and that the population tend to grow old.

Gradual decreases in C P U E and catch in number of urchins also showed the decreasing recruitment. It was estimated that the catch exceeded the recruitment in 1979, and the catch was nearly equal to the recruitment in 1980. It was concluded from these results that the stock size of *S. intermedius* in Akkeshi Bay is declining and, therefore, the effort of fishing more than the present level should be avoided.

The stock abundance of *S. intermedius* in Akkeshi Bay was calculated by three different methods, the stripe-fishing method, the DeLURY method and the BARANOV-RICKER method. The amount estimated was 690 (1973) –2600 (1974) metric tons by stripe-fishing method, 300 (1980) –630 (1976) metric tons by the DeLURY method and 810 (1980) –1600 (1977) metric tons by the BARANOV-RICKER method. The differences in the estimates must have been caused by differences in preconditions applied. A comparatively high accuracy in stock size value should be obtained when calculation is made with each age group in BARANOV-RICKER method compared with the other two method in which age composition of the population is not considered.

The age determination by use of pigmented-growth lines on the 5th genital plate showed that the management of sea urchin stocks would be greatly improved through making it possible to estimate correct age composition necessary for population analyses.

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In the analysis of the stocks of useful fish, one establishes the ages from the growth lines in the rings seen on the otoliths, scales and vertebrae, and so one finds the age composition of the concerned biological groups. To determine the stock size of sedentary organisms represented by urchins first, there is the method examining the fishing grounds and proceeding on the basis of the "product of the density by the inhabited area" (density-area method). Another common method is to use the fisheries statistical data to find the state of the stock through the "relationship between the volume of catch per unit effort and the accumulated catch volume (De Lury method)[1-3]. There is virtually no estimation of stock size using the age composition.

In biological resources two elements are continually at work and changing viz. reproduction (birth) which endeavours to increase the above stocks and death acting in the opposite direction. If as in the case of the urchin fisheries in Akkeshi, there is a relatively long fishing season (3 months from December to February)[4], there is concern that the urchin stock size cannot be known exactly when using a stock size evaluating method giving no consideration to the aspects of death and recruitment.

In our former report[5-8] we explained that the growth lines forming in the high part of the growth gradient of the shell plate are formed during the winter, and that these so-called winter rings constitute annual rings. In this study we used the annual rings on the shell plate of Strongylocentrotus intermedius* in Akkeshi to investigate

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Translator's note:

* Abbreviated in the remainder of the present translation as Si.

the ages and to analyze the stock. We also compared with the results obtained through the traditional methods of evaluating the sizes of the same stocks.

At the start of this article, I wish to thank professors Juro** YAMADA, Ken'ichiro KUNI**, Akira FUJI of the Fisheries Department, Hokkaido University who gave me much advice and who revised my work, Mr. Yutaka KITANO, Head of the Resources Department at the Japan Sea Laboratory who helped me with the methods of stock analysis and computer calculations. I also thank the personnel of the Kushiro Eastern Fisheries Advisory Center and of the Akkeshi Fisheries Cooperative for giving me much help in the course of the present survey.

Materials and methods

In March 1977, we used diving equipment to collect Si urchins around the two Daikokujima and Oshima islands in the Akkeshi Bay. We investigated by the Jensen[9] method the growth lines (annual rings) of the genital plates, found the average shell diameters by age and obtained the mode of growth by applying these to the Bertalanffy formula. With regard to age composition, age determination was carried out from 1977 to 1980. For the other data we followed Doi[10,11] on the basis of the measurement registers and found our results by preparing the correlation between age and shell diameter. For evaluating the amounts of stocks, we relied on the catch analysis method (Baranov-Ricker method) used by Sengoku[12], Kitano-Ida[13] for the

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Translator's note:

** Reading not quite certain; same hereafter for names marked **.

Alaska ocean perches of the North Pacific and the northern red shrimps* of Western Kamtchatka. We evaluated the various sizes of stock by the traditional density-area method, the De Lury method and compared with the estimated stock sizes found by the catch analysis method. As for the amounts of catch, operation times and other fisheries statistical data, we obtained the information from the urchin fisheries operators journals and from the data of the Akkeshi Fisheries Cooperative. For the calculations, we used a SEIKO S-500 desk computer. For the terminology used in the stock analysis, we followed Holt et al[14] and Awata.[15]

Results

1. Urchin operations in Akkeshi

Urchin fishing grounds distribution: The urchin fishing grounds in the Akkeshi Bay extend around the two islands of Daikokujima and Kojima at the mouth of the bay and along the reef band of the eastern coast. It is largely divided into the 4 following areas viz. 1) the zone surrounding Daikokujima, Kojima at the mouth of the bay and the Mabiro area, 2) the central shallow area of reefs in the center of the bay, 3) the area from the mouth of the bay to the inner part along the eastern coast, that is from the Aininkappu cape to the Barasan cape and 4) the area going from Chinbenohana to kujirahama along the eastern coast outside the bay (Fig. 1). Fishing is carried out in this fishing ground every year from December to February of the following year, using diving gear.

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*Translator's note: Literal translation.

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Amount of catch Table 1 shows for 1977 the amounts of catch and operating times for the particular areas. Of the total catch, 86% is taken from around the two islands of Daikokujima and Kojima and in the waters near Mabiro. This area is the main urchin fishing ground. As the waters are clouded in the other areas, the operating time is restricted (Nakase), and outside the Akkeshi Bay, going to the fishing grounds and coming back takes time. The operating time depends also on the weather (Chinbenohana - Kujirahama) so that the use of the fishing grounds is limited. In these fishing grounds the percentages of operating time and of volume of catch are roughly similar every year.

As Table 2 shows, the total amounts of urchin catch per year in Akkeshi were in the 260-410 ton range. There was in increasing tendency from 1971 to 1977 but decrease from 1978. p. 35

2. Growth and age composition

Growth: Table 3 shows the average shell diameter of Si in Akkeshi per age. Applyig this to the Bertalanffy growth formula we obtained

$D = 103.030\ [1-e^{-0.184(t+0.030)}]$ (Fig. 2).

We have the $W = A \cdot D^n$ (D: shell diamter; W: weight) relationship formula between the shell diameter of urchins and the weights[16,17]. This relationship is given in Table 4 with regard to catch investigation samples from 1973 to 1980. The 1977 weight increase coefficient is 2.757. Thus the weight growth equation is $W = 372.332\ [1-e^{-0.184(t+0.030)}]^{2.757}$. The age is represented by t.

We used the particular shell diameters and weights by age obtained by these growth formulae as theoretical values (Table 5). These theoretical values resemble closely the actual readings. It seems therefore that the Si of Akkeshi exhibit a growth following the above formulae. The age used here represents full years of age. We counted the 12 months following spawning as 1 year and the 24 months after the same as 2 years.

Age composition: Fig. 3 shows the age composition from 1973 to 1980 obtained through the age determination and the table of relationship between age and shell diameter[10,11]. From 1973 to 1975, the main group in the age composition is made of 4-year urchins. In 1977, 5 year-and-more aged urchins increase in number. This trend grows stronger again from 1978. It seems that the growth of Si individuals in Akkeshi show a tendency toward ageing. There are almost no 3 year or less urchins in the actual catch. The target of urchin fisheries is 4 year or more urchins, and this age composition is about equal to the composition of the 4 year and more urchins obtained in the fishing grounds survey. After 1975 the aged individuals increase in number and there are less young individuals.

3. Stocks analysis

If we assume that the number Nt of t year individuals of a given generation year class group becomes Nt+1 in the next year (t+1), then the survival rate S shows $S = \frac{Nt + 1}{Nt}$ (1), and if we express by 'a' the death rate, by S the survival rate and by Z the total momentary death coefficient, and if we express by F the capture momentary death

coefficient and by M the natural momentary death coefficient, then we obtain the following relationships viz.

$$a = 1-S \qquad (2)$$

$$S = e^{-Z},\ Z = -\ell nS \qquad (3)$$

$$Z = M+F \qquad (4)$$

From moment t to t+1 the number of deaths is

$$Nt \cdot a = Nt\ (1-e^{-Z})$$

If this is distributed by formula (4) in natural death and death by capture, then

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natural death $\frac{M}{Z} Nt\ (1-e^{-Z})$

death by capture $\frac{F}{Z} Nt\ (1-e^{-Z})$

If the death by capture is shifted as Ct, then we have

$$Nt = Ct \frac{Z}{F(1-e^{-Z})} \qquad (5)$$

From these we know Ct, Z and F, and are able to estimate the stock size Nt.

Thereafter, we estimated the volume of recruitment, following the method of Sengoku[12]. The number Nti of t-years-old fish in the stock at the beginning of i years of fishing decreases by capture and natural death at the end of the i years of fishing, and we have

$$Nti' = Nti \cdot e^{-(Fi+M)}. \qquad (6)$$

p. 38

This is the number of t+1-years-old individuals surviving from the previous year at the beginning of the i+1 years fishing period. Meanwhile the (Nt+1, i+1) number of t+1-years-old urchins of the stock at the beginning of the i+1 years fishing season counted through equation

(5) from the number of captured t+1-years-old urchins at i+1 years contains the volume (R) of recruitment of t+1-years-old urchins at i+1 years. Therefore one can estimate the recruitment from the difference between these two. That is, the recruitment of t+1-years-old fish at i+1 years is

$$R_{t+1,\ i+1} = N_{t+1,\ i+1} - N_{ti} \quad (7)$$

The stock size of recruitment beginning age corresponds without any change to the recruitment of the year.

CPUE and number of individuals captured: If we divide the weight of catch from 1973 in the compiled comparative data by the number of operating hours by year, we obtain the weight of catch unit effort in each year. If we divide this by the average weight of the individual urchins by year, we find the number of individuals fished by unit effort (Table 6). From 1976, the CPUE declined in terms of both weight and number of individuals.

Stock characteristic values: The most common method of finding the survival rate and the total momentary death coefficient is based on the age composition[11,18]. We considered with regard to the urchins of Akkeshi that the number of individuals caught by age per unit effort shown in Table 7 represents the survival stage of the individuals. Using formula (1) we obtained the survival rate per age with regard to urchins from the 4 years of recruitment completion, and considered this average value as the annual survival rate. The respective survival rates for the 6-year urchins of both 1974, 1978 and for the 5-year urchins of 1980 were calculated to be 1.042, 1.198, 1.245. As a

survival rate of 1.0 or higher is not even theoretically possible, we calculated here respectively as 0.900. Then, we converted the annual average survival rate to the total momentary death coefficient. p. 39 However, since the 1976 age composition is missing, we used the Sengoku[12] method to estimate the age composition of the year. It was difficult to find the natural momentary death coefficient. So we put it at 0.200, using the stock weight by age method of Doi[19]. We found the capture momentary death coefficient from the total momentary death coefficient and from the natural momentary death coefficient. From these characteristic values we estimated the catch rate to be 0.251~0.441 and the natural death rate 0.134-0.156 (Table 8).

Initial stock size: Recruitment is practially completed in 4 years for the urchins of Akkeshi. So to find the initial stock sizes we used formula (5) for the 4 year-or-more fish (Table 9). Moreover, we substituted the stock characteristic values of 1979 in the evaluation of the 1980 stock size. The number of individuals in the initial stock is 6 million-19 millions. There is some decrease in 1974 and 1976 but 1977 saw a return to the levels of 1973 and 1975. From 1977 however, there is a declining trend. Moreover from 1975, the relatively young 4-year, 5-year urchins decrease and there is a relative increase in aged 8-year urchins. Except for 1974, the stock weight shows an increasing trend up to 1977, but there is a decrease in number of individuals in the stock as well as in weight from 1978.

Relationship between recruitment and catch volume: Fig. 4 compares by year the initial stock size, the recruitment and the catch volumes. We found the recruitment from 1974 to 1980, using equation (7).

From 1975, the recruitment and catch volumes show a declining trend, and recruitment dropped sharply from 1977. Then the difference between catch and recruitment volumes began to decline gradually and in 1979 the catch exceeded the recruitment. In 1980 the catch and recruitment were almost at the same level. Carrying out fishing that exceeds recruitment depletes the target stock and there is a risk that this affected the stock size and catch from 1981. As for the drop in recruitment starting in 1978, there seems to have been a gradual decrease because of the great fishing efforts. p. 40

4. Comparison with the estimation results based on the various methods of estimating the stock sizes

Table 10 shows the values estimated, using respectively the density - area method (stripe-fishing method), the De Lury method and the catch analysis method (Baranov-Ricker method). The stock size estimation values obtained by these 3 methods are at variance. This seems to be due to the different preliminary conditions used prior to using these various methods. For instance, the stripe-fishing method is frequently used to evaluate the stocks of organisms having a sedentary mode of life, and the precondition is that one extracts samples reflecting the distribution density of the target organisms. The precision of the estimated values depends on whether this preliminary condition is fulfilled or not. So when surveying a wide fishing ground, the number of samples will be small if the survey hours, presonnel and number of survey boats are limited.

In the De Lury method (Fig. 5) the target group of the individual organims is closed. This is because of the precondition that there is no decrease due to natural death or migration, or no increase

due to recruitment during the fishing period, that the total fishing ground is used uniformly without unevenness in unit periods and that the fishing intensity is constant regardless of the stock size. These conditions were satisfied in the Akkeshi area urchin fishing grounds around Daikokujima and Kojima and in the Mabiro area only. In the other parts of the fishing grounds there were few operating hours and the catch was small (Table 1). Because of the unbalanced usage of the fishing grounds, the present method cannot be used.

In the Baranov-Ricker method, one must survey exactly the age of the fish, and the age composition of the catch must represent the composition of the group of individuals. The urchin operations in Akkeshi involved diving gear. As there is no particularly great limitation with regard to catch size, operation time and fishing ground use, the age composition of the catch seems to represent roughly the composition of the group of individual urchins in Akkeshi. The birth and death rates of the groups of individual organisms differ according to the size and age structure of these groups of individuals. This is only compared to the 2 above methods, this method finding the stock size per age seems to be the most precise. Yet, as this method also uses the fisheries statistical data, its defect is that similarily to the De Lury method it can estimate only the size of the target group.

Discussion p. 41

The size of a group of individuals increases or decreases depending on birth and death. These can be estimated on the basis of the age composition of the group and of the catch size. Therefore, the

first condition to analyze and interpret the target stock is to know the age composition of the group. If one does not survey properly the age of the target individuals, it is impossible to obtain correct values characteristic of the stock, and in the end one performs erroneous stock analysis and interpretation. This affects greatly the stock management.

The present study revealed with respect to the age composition of the group of Si individuals in Akkeshi that the recruitment of young individuals declined since 1975, that there was an increase in older individuals and that the group as a whole showed an ageing trend. We also noted that the total number of individuals caught and the CPUE tended to decrease, that recruitment declined from 1975, that the catch exceeded the recruitment in 1979 and that it was at about the same level as recruitment in 1980. These findings show that the urchin stock in Akkeshi is deteriorating. In order to maintain the stock, one should therefore avoid increasing the fishing effort and one should watch closely the future conditions of the stock.

In the past, the stripe-fishing or De Lury methods were commonly used to evaluate the stock size of sedentary organisms such as urchins and shells[1-3]. These methods lower the precision of the stock size estimation values because of the method of extracting specimens. Another defect is that of obtained erroneous results if no close attention is paid to the preliminary conditions. The birth and death rates of the groups of individuals differ according to the stock size and age composition. Therefore the catch analysis method (Baranov-Ricker method) finding the stock size by age is more precise than the above 2 methods which do not consider the age composition. Therefore, the difference between the results obtained by the 2 above methods show

the importance of the age survey in the estimation of stock size. Knowing the age composition and tendencies of a group of individuals on the basis of the annual rings observed in hard tissues such as the otolith, vertebrae, scales, shells of the target organisms, and finding from correct stock characteristic values highly precise stock size estimation values are important elements for safe stock management.

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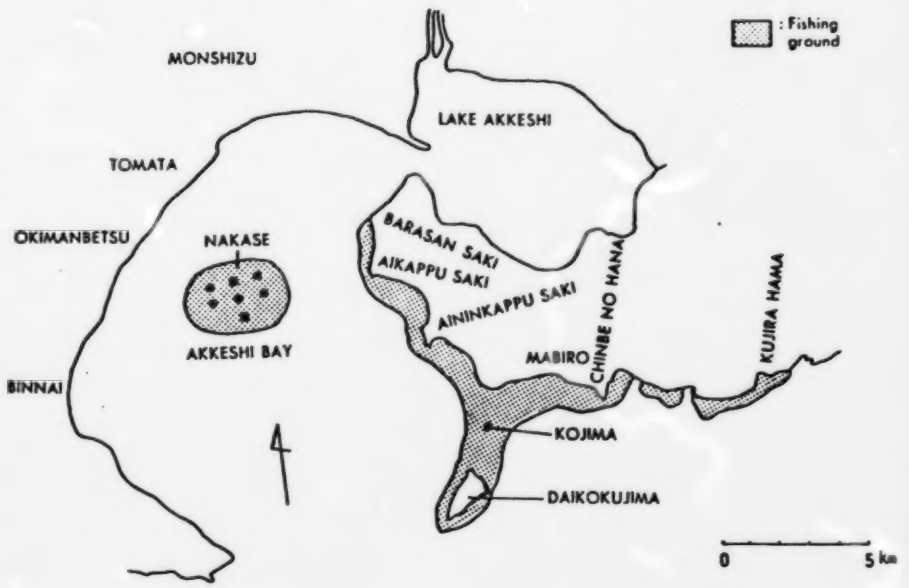

Fig. 1. Fishing ground of sea urchin, *S. intermedius*, in Akkeshi Bay.

Table 1. Catch and effort on the fishing ground of sea urchin, *S. intermedius*, in Akkeshi, 1977.

Fishing ground	Effort in hours		Catch in metric tons	
	Effort	Rate(%)	Catch	Rate(%)
Nakase	270	4.5	19	4.6
Barasan Saki-Aininkappu Saki	222	3.7	14	3.4
Daikokujima-Mabiro	5161	85.7	356	86.4
Chinbe no hana-Kujira hama	366	6.1	23	5.6
Total	6019	100.0	412	100.0

Table 2. Annual catch of sea urchin, *S. intermedius*, in Akkeshi.

Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Catch (Metric tons)	258	276	368	317	355	374	412	340	338	261

Table 3. Average test diameter estimated from pigmented-growth lines on the genital plates.

No. of growth lines	I	II	III	IV	V	VI	VII
Average test diameter	18.5± 0.61	34.1± 0.66	43.6± 0.71	52.6± 1.25	61.0± 1.26	68.3± 3.10	75.6± 4.30

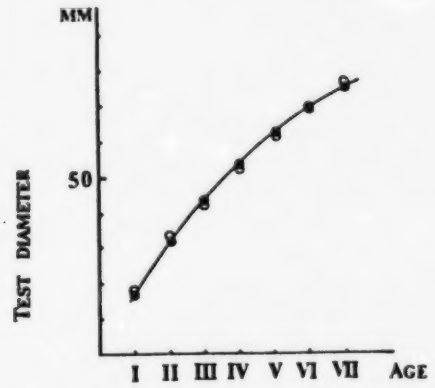

Fig. 2. Growth curve of the test diameter of *S. intermedius* in Akkeshi. Black and open circles indicate theoretical and actually measured values, respectively.

Table 4. Regression between the test diameter (D) and the total weight (W) of *S. intermedius* in Akkeshi.

Year	Regression formula
1973	$W = 0.991 \times 10^{-3} D^{2.754}$
1974	$W = 0.586 \times 10^{-3} D^{2.889}$
1975	$W = 0.732 \times 10^{-3} D^{2.837}$
1977	$W = 1.050 \times 10^{-3} D^{2.757}$
1978	$W = 0.644 \times 10^{-3} D^{2.879}$
1979	$W = 0.620 \times 10^{-3} D^{2.887}$
1980	$W = 0.632 \times 10^{-3} D^{2.876}$

Table 5. Theoretical values of test diameter and weight of *S. intermedius* calculated by growth formulas.

Age	I	II	III	IV	V	VI	VII	VIII
Test diameter(mm)	17.79	32.11	43.03	53.95	62.20	69.06	74.77	79.52
Weight (g)	2.94	14.97	35.73	62.55	92.60	123.57	153.83	182.30

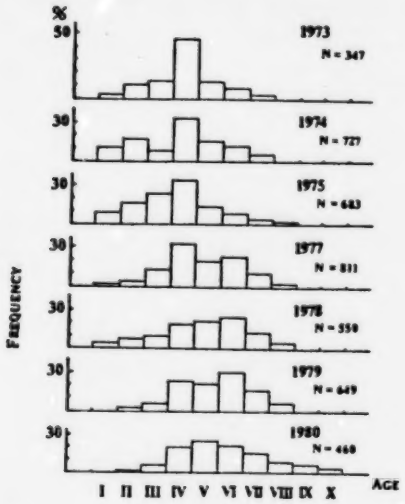

Fig. 3. Age composition of *S. intermedius* in Akkeshi.

Table 6. Catch per unit effort of *S. intermedius* in Akkeshi.

Year	1973	1974	1975	1976	1977	1978	1979	1980
Catch (metric tons)	368	317	355	374	412	340	338	261
(number $\times 10^3$)	6434	5428	6814	6361	4876	3917	3304	1968
Effort (hours)	5775	4936	5203	5554	6019	5441	6752	5928
CPUE								
Catch (weight Kg)	63.7	64.2	68.2	67.3	68.5	62.5	50.1	44.0
(number)	1113.6	1099.3	1309.0	1144.6	810.7	720.0	489.7	331.8

Table 7. Catch number per unit effort by age groups of *S. intermedius* in Akkeshi.

Year	IV	V	VI	VII	VIII	IX	X	Total
1973	720.5	200.4	122.5	61.3	8.9			1113.6
1974	548.6	247.3	208.9	87.9	6.6			1099.3
1975	755.3	301.1	171.5	70.7	10.4			1309.0
1976	587.1	228.9	176.3	119.0	33.2			1144.5
1977	287.8	174.3	220.5	106.2	21.9			810.7
1978	177.1	188.6	208.8	113.8	31.7			720.0
1979	68.6	90.1	156.7	139.6	34.8			489.8
1980	70.2	85.4	74.0	54.9	29.0	13.0	5.3	331.8

Table 8. Parameters used for calculating the stock size of *S. intermedius* in Akkeshi.

Year		1973	1974	1975	1976	1977	1978	1979
Survival rate	S	0.517	0.425	0.513	0.512	0.593	0.579	0.531
Total mortality coefficient	Z	0.660	0.856	0.667	0.669	0.523	0.546	0.633
Fishing mortality cofficient	F	0.460	0.656	0.467	0.469	0.323	0.353	0.433
Natural mortality coefficient	M	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Exploitation rate	E	0.337	0.441	0.341	0.342	0.251	0.267	0.321
Unconditional natural mortality rate	D	0.146	0.134	0.146	0.146	0.156	0.154	0.148

Table 9. Initial stock size by age group (individuals$\times 10^3$) of *S. intermedius* in Akkeshi.

Year	IV	V	VI	VII	VIII	IX	X	Total	Weight
1973	12366	3440	2103	1052	152			19113	1400 t
1974	6148	2771	2340	985	75			12319	997
1975	11521	4593	2617	1079	161			19971	1511
1976	9532	3716	2863	1934	537			18582	1559
1977	6887	4171	5276	2541	524			19399	1639
1978	3611	3846	4258	2321	647			14683	1275
1979	1442	1894	3295	2935	732			10298	1054
1980	1297	1579	1368	1015	536	240	99	6134	813

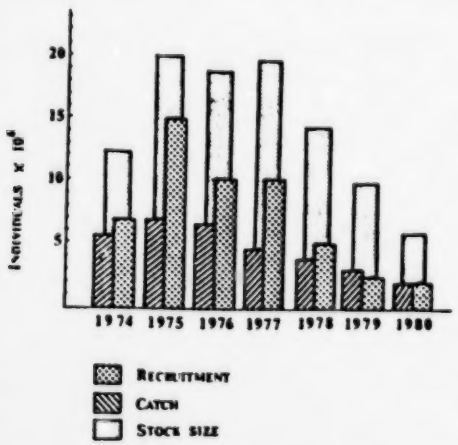

Fig. 4. Comparison of stock, recruitment and catch of *S. intermedius* in Akkeshi.

Table 10. Annual stock size (metric tons) of *S. intermedius* in Akkeshi estimated by three different methods.

Methods \ Year	1973	1974	1975	1976	1977	1978	1979	1980
Strip-fishing	694	2603	1126	–	1207	1319	2302	2092
Baranov-Ricker	1400	997	1511	1559	1639	1275	1054	813
Delury*	–	–	530	634	604	456	403	308

* Applicable to Daikoku Jima, Kojima and its adjacent area

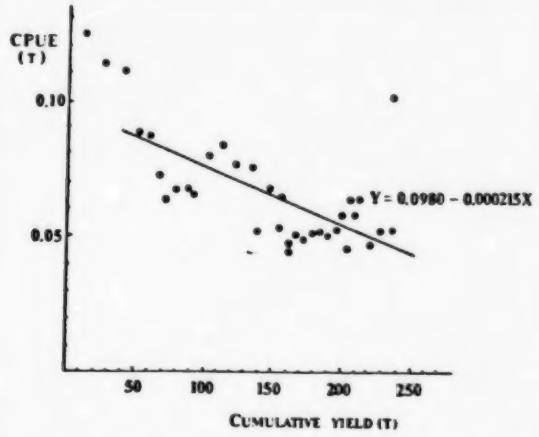

Fig. 5. Relation between the catches per unit effort and the cumulative yield of *S. intermedius* in Akkeshi, 1978.

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